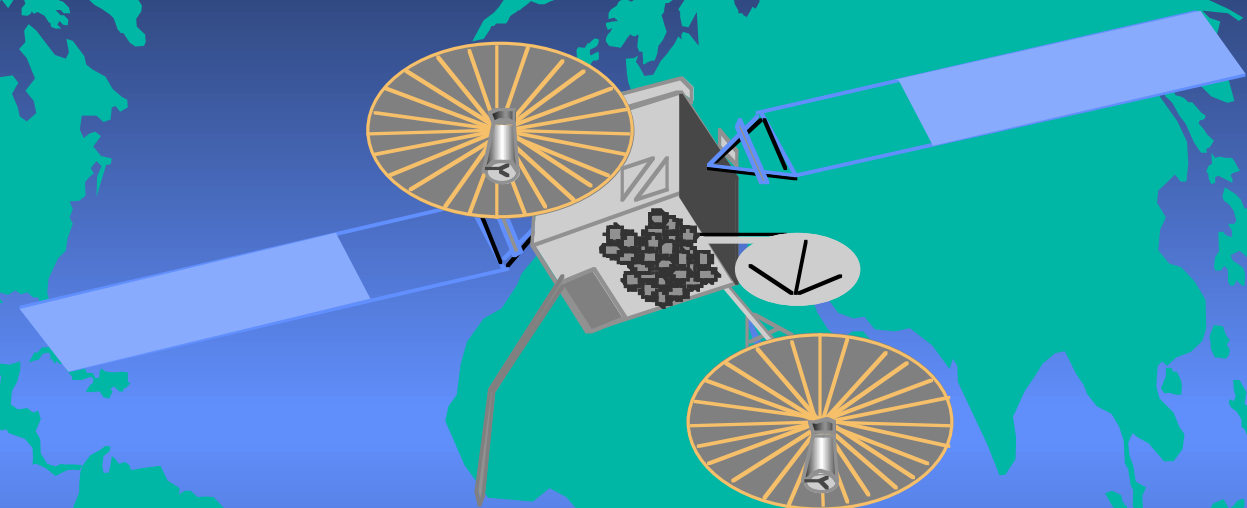


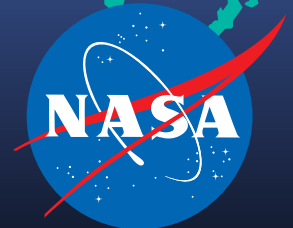
NASA's Tracking and Data Relay Satellite System Ka-Band Technology Development Activities

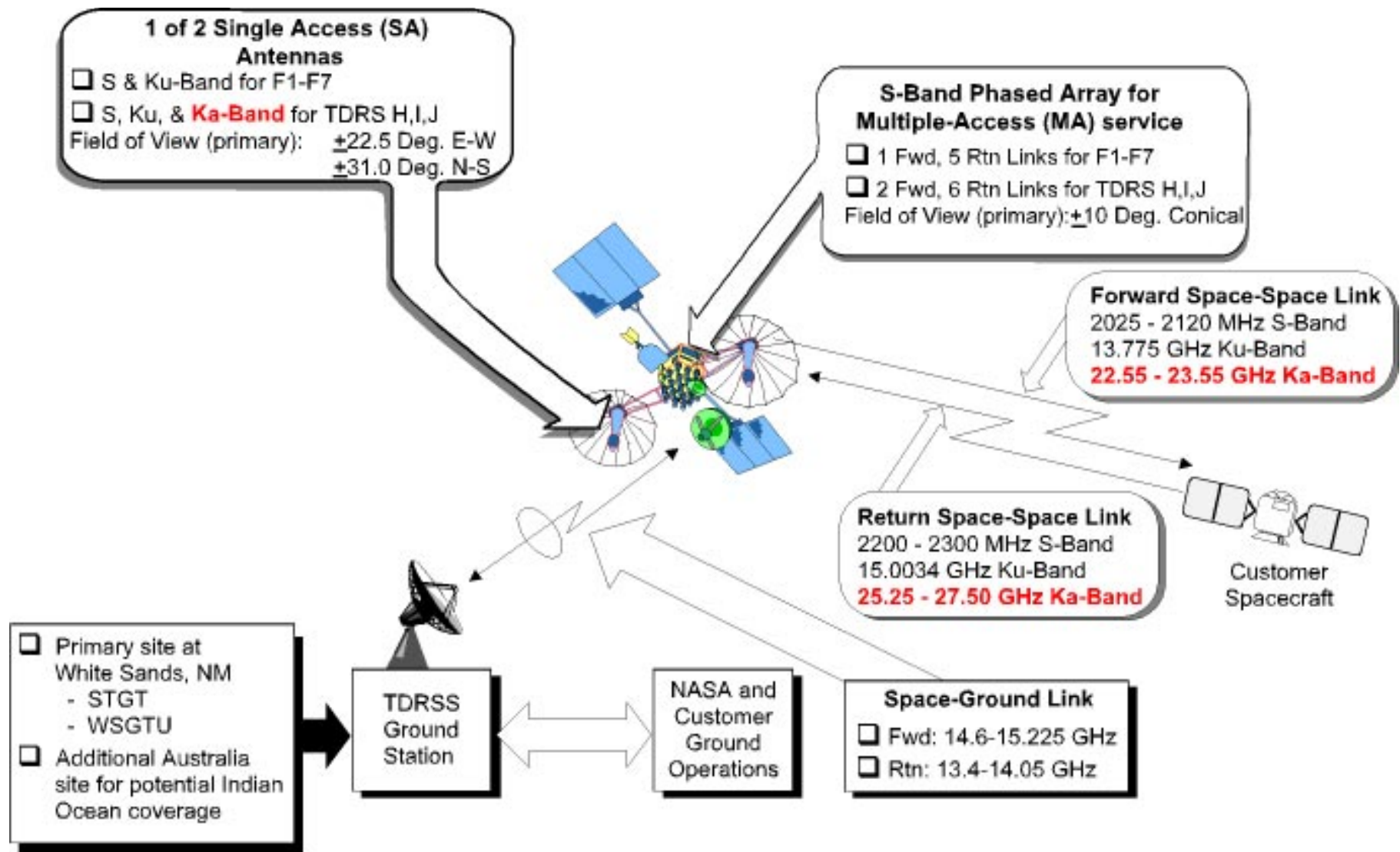


Second Ka Band Utilization Conference
September 24-26, 1996
Florence, Italy

Badri Younes, CLASS Project Manager
Anthony Comberiate, TDRS Deputy Project Manager
David Zillig, RF Systems Section
Thomas Ryan, Ground Systems Study Manager
Joseph Deskevich, Spectrum Management
Mark Burns, Stanford Telecommunications
Ronna Brockdorff, Stanford Telecommunications

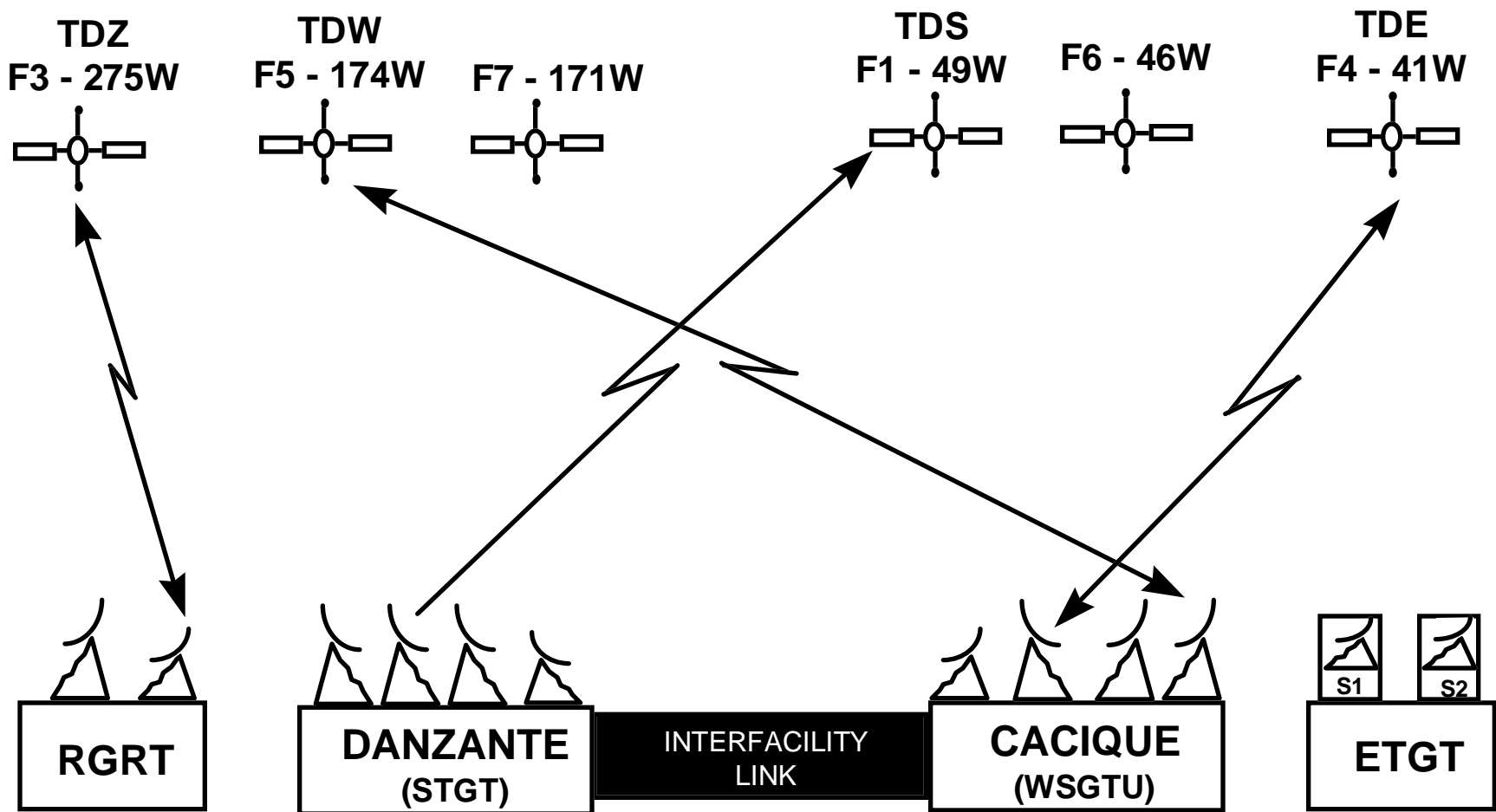
STel[®]





TDRSS Communications Components

The Tracking and Data Relay Satellite System (TDRSS) and supporting facilities provide nearly continuous interface to communicate with and control most NASA near-earth orbital mission.



Current TDRS Constellation

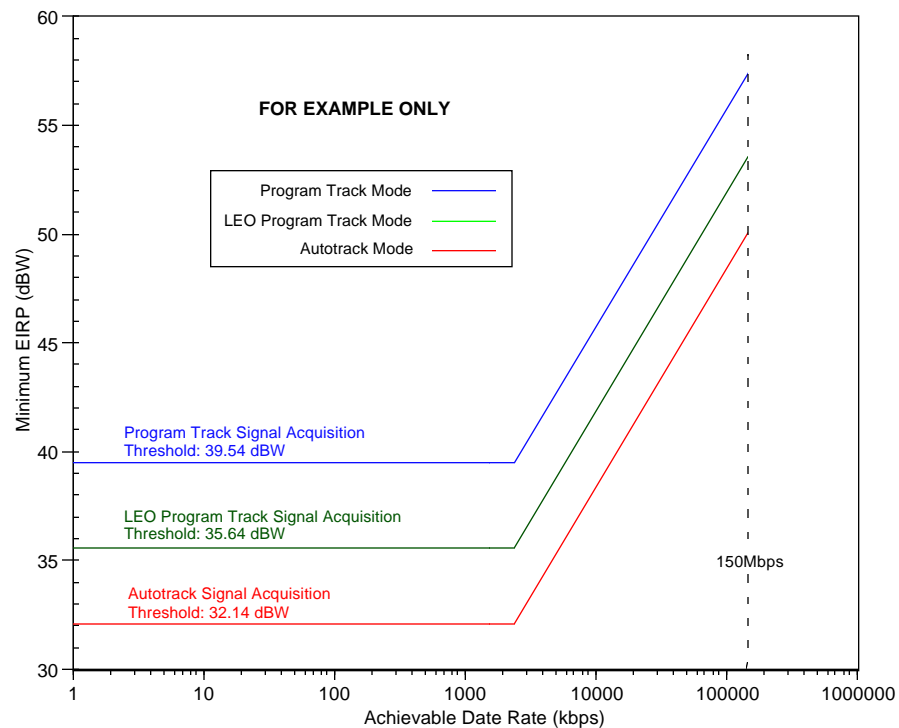
- **TDRS H,I,J are NASA's next generation tracking and data relay satellites that will replenish and augment the existing TDRSS constellation**
- **Includes new Ka-band services and enhanced S-band multiple access services**
- **Backwards compatibility with existing TDRSS users**
 - **S-band multiple access telecommunications and tracking services**
 - **S-band single access telecommunications and tracking services**
 - **Ku-band multiple access telecommunications and tracking services**
- **Scheduled launches: July 1999, July 2000, and July 2001**

TDRS H,I,J Overview

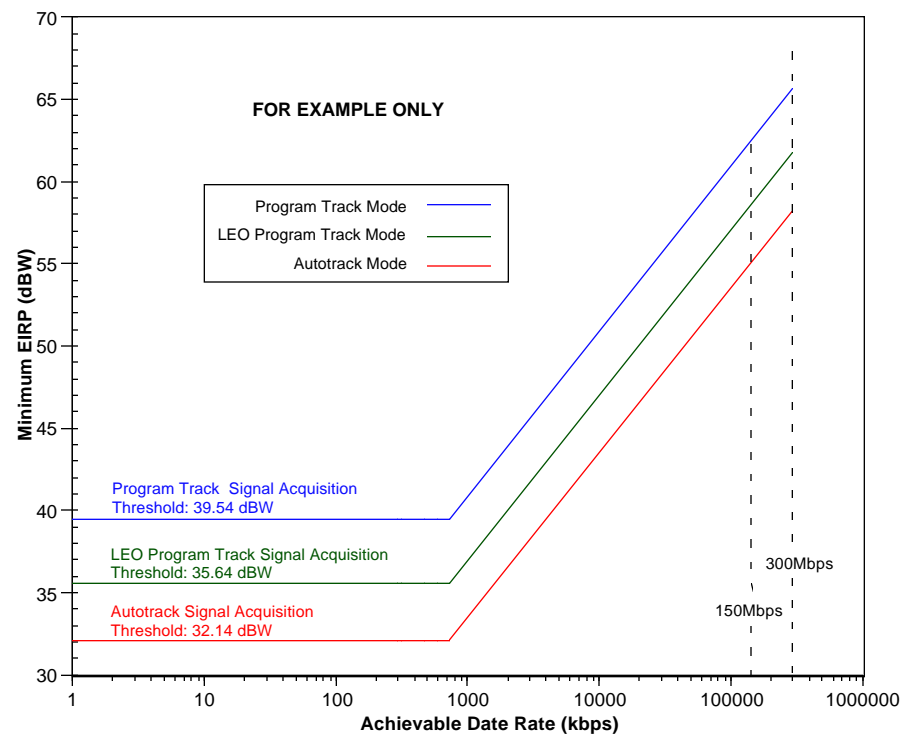
SERVICE			TDRS 1-7	TDRS H,I,J	NOTES
SINGLE ACCESS	S-BAND	FWD	300 kbps	300 kbps	NO CHANGE
		RTN	6 Mbps	6 Mbps	
	Ku-BAND	FWD	25 Mbps	25 Mbps	NO CHANGE
		RTN	300 Mbps	300 Mbps	
	Ka-BAND	FWD	N/A	50 Mbps	FWD: 22.55 - 23.55 GHz (in 5 MHz steps) RTN: 25.2534 -27.4784 GHz (in 25 MHz steps and 225 MHz BW) 25.55 - 27.5 GHz (in 25 MHz steps and 650 MHz BW)
		RTN	N/A	300 Mbps (1)	
	NUMBER OF LINKS PER SPACECRAFT		2 SSA 2 KuSA	2 SSA 2 KuSA 2 KaSA	For TDRS H,I,J simultaneous operation of S & Ku and S & Ka services via a single SA antenna is required
NUMBER OF MULTIPLE ACCESS LINKS PER SPACECRAFT		FWD	1 @ 10 kbps	2 @ 10 kbps (2)	Anticipated SSA users < 3 Mbps off-loaded to TDRS H,I,J MA
		RTN	20 @ 50 kbps	6 @ 1.5 Mbps	
CUSTOMER TRACKING			150 meters 3 sigma	150 meters 3 sigma	NO CHANGE
NOTES: 1. Capable of supporting 800 Mbps with upgrades to the ground station (1 per spacecraft). 2. EIRP is adjustable in 1 dB steps from 34 to 42 dBW, which is 8 dB above TDRS 1-7.					

TDRS/TDRS H,I,J Baseline Service Comparison

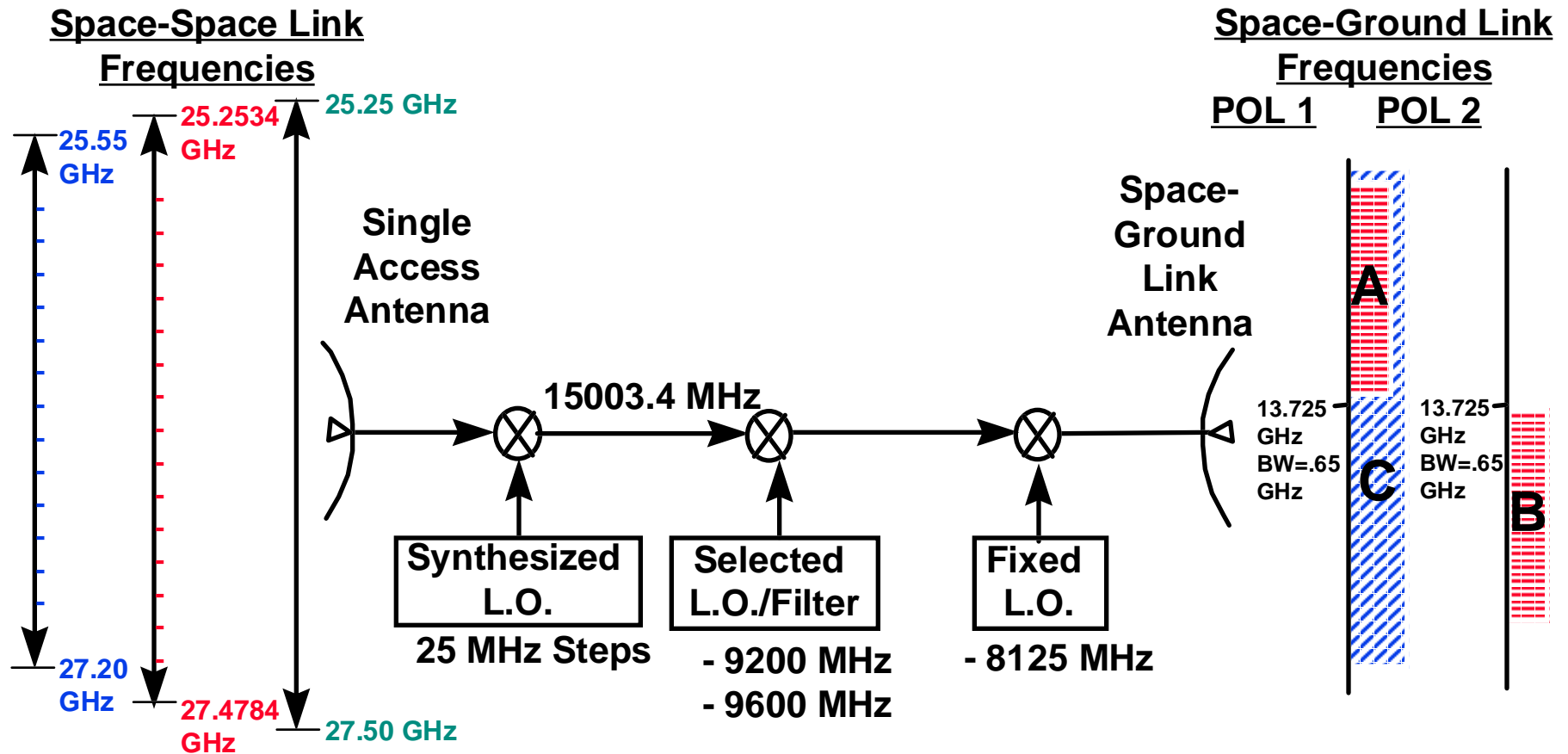
KaSAR, Rate 1/2 Convolutional Coding



KaSAR, Uncoded



Return Service Achievable Data Rates



- **Total Service BW = 2.25 GHz**
- **90 Selectable "Narrowband" Channels** (81 Capable of Full 300 Mbps)
- **66 Selectable Wideband Channels** (over 300 Mbps Capacity)

- **Two Services Simultaneous**
- **Channels A&B BW = 225 MHz (min)**
- **Channel C Bandwidth = 620 MHz** (800 Mbps Capacity)

TDRS H,I,J Ka-Band Spacecraft Return Service Flexibility

- **NASDA (Japan) and ESA (European Space Agency) are currently implementing data relay satellite systems that will include Ka-band forward and return services**
 - **NASDA will have 3 Data Relay and Tracking Satellites (DRTS) providing S-band, Ka-band, and optical communications and data services.**
 - ❑ **COMETS (a DRTS Prototype), located at 121 Degrees East Longitude**
 - ❑ **DRTS-1, located at 90 Degrees East Longitude (DRS-West)**
 - ❑ **DRS-2, located at 170 Degrees West Longitude (DRS-East)**
 - **ESA will have 1 Data Relay Satellite (DRS) initially and potentially 2 additional in the post 2000 time period providing S-band, Ka-band, and optical communications and data services.**
 - ❑ **Artemis (a DRS Prototype), located at 6 - 19 Degrees East Longitude**
 - ❑ **DRS-1, located at 59 Degrees East Longitude (DRS-East)**
 - ❑ **DRS-2, located at 44 Degrees West Longitude (DRS-West)**
- **NASA has entered into a Ka-band interoperability agreement with NASDA and ESA as a result of SNIP study activity**
- **A SNIP technical recommendation was developed to ensure interoperability among systems in the event a failure or a requirement for additional customer coverage**

Ka-band Interoperability

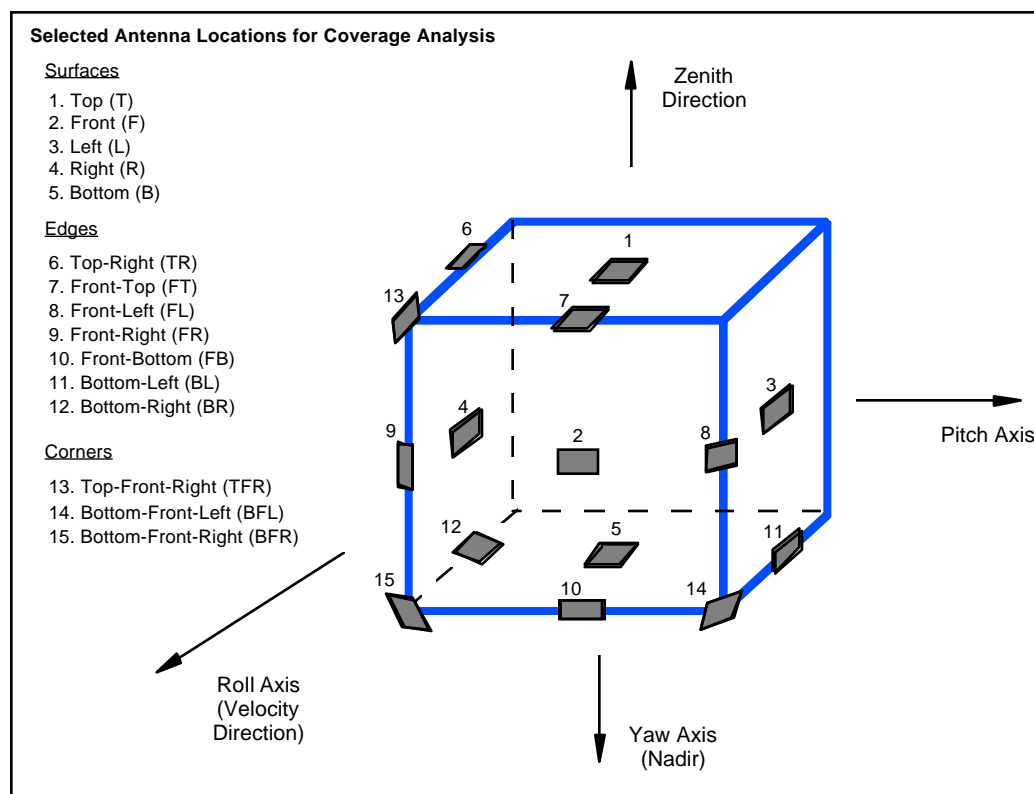
Link Budgets	<div> <div>EIRP towards User S/C</div> <div>G/T towards User S/C</div> </div> <div> <div>ESA DRS</div> <div>61.3 dBW</div> <div>22.3 dB/K</div> <div>auto-track</div> </div> <div> <div>57.3 dBW</div> <div>19.3 dB/K</div> <div>open-loop pointing</div> </div> <div> <div>NASDA DRTSS</div> <div>61.5 dBW</div> <div>26.5 dB/K</div> <div>auto-track</div> </div> <div> <div>59.0 dBW</div> <div>24.0 dB/K</div> <div>open-loop pointing</div> </div> <div> <div>NASA TDRS H,I,J</div> <div>63.0 dBW</div> <div>26.5 dB/K</div> <div>auto-track</div> </div> <div> <div>59.5 dBW</div> <div>23.0 dB/K</div> <div>open-loop pointing</div> </div>
Field of View	+10° conical about the DRS-to-Earth center axis
Forward Link Frequency Framework	DRS IOL Center Frequencies selected from: 23.205 GHz 23.265 GHz 23.325 GHz 23.385 GHz 23.445 GHz 23.505 GHz Minimum bandwidth of 50 MHz
Return Link Frequency Framework	DRS IOL Center Frequencies selected from: 25.60 GHz, 25.85 GHz, 26.10 GHz, 26.35 GHz, 26.60 GHz, 26.85 GHz, 27.10 GHz, 27.35 GHz Minimum bandwidth of 225 MHz
Polarization	LHCP and RHCP (same polarization for forward and return)
Polarization Purity	DRS IOL Antenna Axial Ratio: ≤1.5 dB over the 3 dB beamwidth
Forward Beacon for user spacecraft antenna acquisition	Either: 1) an unmodulated carrier, transmitted with the same frequency and polarization as the user forward IOL signal OR 2) a wide-beam beacon, transmitted on LHCP at one of the following frequencies, selected in coordination with the other SNIP participating Agencies: 23.530 GHz, 23.535 GHz, 23.540 GHz, and 23.545 GHz The reference signal EIRP towards the User Spacecraft should be 24 dBW, minimum.
Return Signal Tracking	Operate on the modulated signal, at the return frequency selected by the user
Dual-Band IOL Operation	Two-way (fwd/rtn) interoperable IOL service in both S-band and Ka-band simultaneously
User Spacecraft Tracking	No Recommendation
Modulation Scheme	Forward Links: BPSK, QPSK, UQPSK, with no FEC coding Return Links: BPSK, QPSK, UQPSK, either [with FEC coding (R=1/2, k=7)] or with no coding
Data Rates	Forward Links: 100 kbit/s - 25 Mbit/s (BPSK and UQPSK) 100 kbit/s - 50 Mbit/s (QPSK) Return Links: 100 kbit/s - 75 Mbit/s (with coding: BPSK, UQPSK) 100 kbit/s - 150 Mbit/s (no coding; BPSK, UQPSK, QPSK) 100 kbit/s - 150 Mbit/s (with coding; QPSK)

SNIP Ka-band Interoperability Recommendations

- **NASA is currently identifying available space qualified Ka-band technologies with acceptable performance, weight, size, power consumption, and cost.**
 - This will provide a range of options to future missions using TDRS H,I,J as well as direct space-to-earth communications with low cost ground stations.
 - This will allow for high data rates over large bandwidths and reduce the size and weight of spacecraft components.
- **Preliminary results from the technology trade study indicate an increasing base of spacecraft and ground station Ka-band components.**
 - Components of interest include phased array antennas, TWTAs, SSPAs, and high data rate receivers.
 - Technology developments include:
 - * NASA's Advanced Communications Technology Satellite (ACTS) ground terminal that can operate up to 622 Mbps and Monolithic Microwave Integrated Circuits (MMICs) phased arrays
 - * NASDA's Communications and Broadcasting Engineering Test Satellite (COMETS) with 10 and 20 watt SSPAs and 200 watt TWTAs.
 - * ESA's OLYMPUS with Ka-band TWTAs, earth station antennas, and frequency converters
 - * Iridium's planar phased array antennas, state-of-the-art 3.4 watt PAs, and LNAs

Ka-Band Technology Efforts

- **Phased arrays provide a desirable option to LEO satellites that have size and weight constraints combined with the need to transfer large volumes of data.**
- **Because of the overlapping frequency allocations in the 25 to 27 GHz band for space-to-space and space-to-earth communications, a single phased array antenna could provide a user with two options for data transfer.**



Antenna Position (2)	Ground Contacts (3)			TDRSS Contacts (4)		
	No. of Contacts	Total Contact Time (Min.)	Longest Outage (Min.)	No. of Contacts	Total Contact Time (Min.)	Longest Outage (Min.)
3. L	18	127	102	13	1250	37
4. R	16	130	181	14	1166	37
11. BL	23	194	90	25	899	45
12. BR	22	197	91	28	847	40

NOTES:

1. Contact times are for a 24 hour period (approx. 15 spacecraft orbits).
2. Antenna scan angle of $\pm 64.2^\circ$ used to allow horizon-to-horizon viewing (approx. 3.8 dB scan loss).
3. Ground locations used were Alaska, Norway, and Antarctica; 5° elevation mask.
4. TDRSS constellation includes TDRS at 41°W , 174°W , and 275°W .

LEO Spacecraft Visibility Analysis using Ka-Band Phased Array Antenna

ACTS:	Advanced Communications Technology Satellite	NASA:	National Aeronautics and Space Administration
BW:	Bandwidth	NASDA:	National Space Development Agency of Japan
COMETS:	Communications and Broadcasting Engineering Test Satellite	PA:	Power Amplifier
DRS:	Data Relay Satellite	RGRT:	Remote GRO Relay Terminal
DRTS:	Data Relay and Tracking Satellite	RTN:	Return Link (Customer Spacecraft to Relay Satellite Link)
EIRP:	Effective Isotropic Radiated Power	SA:	Single Access
ESA:	European Space Agency	SNIP:	Space Network Interoperability Panel
ETGT:	Extended TDRSS Ground Terminal	SSA:	S-Band Single Access
F1-F7:	TDRS Flights 1 through 7	SSPA:	Solid State Power Amplifier
FWD:	Forward Link (Relay Satellite to Customer Spacecraft Link)	STGT:	Second TDRSS Ground Terminal
IOL:	Inter-orbit Link	TDE:	TDRS-East
KaSA:	Ka-Band Single Access	TDRS:	Tracking and Data Relay Satellite
KaSAR:	Ka-Band Single Access Return	TDRSS:	Tracking and Data Relay Satellite System
KuSA:	Ku-Band Single Access	TDS:	TDRS-Spare
LEO:	Low Earth Orbit	TDW:	TDRS-West
LNA:	Low Noise Amplifier	TDZ:	TDRS in the Zone of Exclusion (ZOE)
L.O.:	Local Oscillator	TWTA:	Traveling Wave Tube Amplifier
MA:	Multiple Access	WSGTU:	White Sands Ground Terminal Upgrade
MMIC:	Monolithic Microwave Integrated Circuits		

Acronyms